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Research article

Study case about the production of masonry concrete blocks with CDW and kaolin mining waste

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Abstract: The worldwide generation of construction and demolition waste is about 30% to 35% of the total solid waste produced annually. In addition, the extraction of minerals leaves a high-grade environmental liability with tailings, such as kaolin clay, Brazil being one of the countries with the largest deposits and production of this mineral in the world. The kaolin clay extraction serves several industries such as ceramics, crockery, and paper, among others. The objective of this work is to insert these two wastes as raw material of construction elements, specifically masonry concrete blocks, thus giving an end to the residues, demonstrating their reutilization potential. Here, blocks were manufactured with replacement of natural aggregates, stone powder, and sand, by construction and demolition waste and of kaolin clay waste. The replacement percentages were up to 34% and 16%, respectively. The blocks made with pneumatic vibration compacting procedure presented strength beyond than what is established by norm, thus giving a favorable perspective of use for these residues as building elements.

Keywords: CDW; concrete block; construction; kaolin clay; residue

1. Introduction

From the first decades of the last century, many urban centers grew inordinately, due to the promise of jobs, improvements in living conditions and migration of the population from other areas in search of opportunities. And mainly peripheral areas and sparsely populated areas became very dense and, consequently, with inadequate infrastructures [1].

The need to meet the demands arising from the disorderly growth of urban centers made civil construction one of the activities in high demand of materials. Making this sector one of the industries that causes the greatest impact on the environment. Constructions without proper planning and supervision cause considerable environmental impacts to the environment due to excessive solid waste generation.

Brazil is an essentially urban country, with more than 80% of the population and most economic activities installed in urban areas. Cities concentrate a large part of the problematic of government management issues. Public authorities at all levels of government have not been able to intervene efficiently in the urban issue. Despite these difficulties, the implementation of instruments, such as the statute of cities, tries to alleviate the difficulties faced by large metropolises. Despite these instruments and guidelines being approved by law, the problem of waste management is still far from over. According to Abrelpe [2], in 2019 the Brazilian percapta production of construction and demolition waste (CDW) was 0.650 kg/inhabitant per day.

Civil construction ends up following the pace of economic growth and development of cities and, consequently, generates high levels of waste. In addition to meeting the housing deficit, there was a need to create urban facilities such as day care centers, schools, hospitals, squares, as well as commercial areas such as shopping centers, to meet the population's increasingly demanding needs.

In another scenario, not very different, the extraction of minerals and ores for the manufacture of industrialized products used as raw material has a great impact on the environment. Extraction techniques end up leaving residues that part of the times they are not reused in the process that generated them or in any other industry. Like the residue from the extraction of kaolin, one of the main ores extracted in the world according to DNPM [3], Brazil is one of the largest producers of this mineral with the main deposits being located in the states of Paraíba, Rio Grande do Norte and northern Minas Gerais.

Kaolin is a mineral associated with pegmatite, which is a variety of granitic rock in which there is similarity with the mineralogical composition, but differing in the sizes of the constituent minerals, which in pegmatite is abnormally large [4]. Kaolin is a clayey material with low iron content, white or almost white color and fine grain size. It is called feldspar the minerals consisting of aluminosilicates of potassium, sodium and calcium, and quartz can be of primary origin (quartzites) or secondary (sands and sandstones) used in ceramics. Clays, due to their plasticity, influence the mechanical strength of samples when they change from green to dry. In the white ceramic and coating industry, various formulations containing raw materials are used to obtain products such as porcelain, bathroom fixtures, tiles and ceramic floors.

Kaolin is a product that results from the process of deep transformation of aluminum silicates, which may be feldspars, plagioclases and feldspatoids, which are contained in rocks. For this transformation to occur, hydrolysis of the silicates takes place with solubilization of alkaline and alkaline-earth ions in the form of carbonates, with the hydrated aluminum silicates remaining insoluble, which crystallize due to high temperature and pressure [5]. The mineral kaolinite, whose formula is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, is the main component of kaolin. It presents in a compact, earthy, microcrystalline mass, 1.0 Mohr hardness, specific weight 2.6 g/cm^3 and low gloss.

According to the mineral summary [3], kaolin mining is processed manually without any covered protection, that is, without a covered deposit. Processing goes through the following phases: first sieving, then it undergoes a decanting and drying process, and then it is heated in a wood oven. Firewood is taken from native trees in the municipality, which are large and small. When already processed, it is transferred to the qualification sector, which is considered good, with a low Fe_2O_3 content, and these are destined for the ceramic industries. When it does not contain the mineral halloysite in its composition, these are destined for the paper industries [3].

As exploration methods are still inefficient, kaolin is extracted together with undesirable materials such as quartz, feldspar and muscovite mica. The separation of kaolin from these materials ends up leaving a high rate of residues that are often deposited near the mining plant itself.

The waste generated and discarded by the kaolin processing industries located in the producing municipalities between the states of Rio Grande do Norte and Paraíba (Brazil) affect the entire surrounding community. Usually, this waste is removed and clandestinely placed in vacant lots, on the banks of rivers and on the streets of the neighborhoods on the outskirts of cities.

CDW and kaolin extraction waste in Brazil are important environmental liabilities because they are deposited in large volumes and are often subject to inadequate disposal. The impacts caused by inadequate waste management affect the environment and people's health, compromising the well-being and, in the long term, even the survival of the human species [6].

In the search for a product that would meet the simple and common need for civil construction, we incorporated kaolin and CDW waste in the masonry blocks, as this is a constructive element widely used in the construction of buildings.

The various studies on the use of waste in the construction sector have been growing visibly in recent decades, seeking to improve cheap and simple construction techniques, always having a sustainable vision for replacing materials conventional [7]. With this expressive expectation, these proposed materials have a high potential for use for this purpose.

Kaolin residues have been used in other research [8] to replace aggregate in the production of ceramic bricks and roofing. As kaolin residue has kaolinite (a pozzolanic material) in its composition, as a result, specimens were burned at different temperatures. The results showed that a residue composed of quartz, kaolinite and mica allows formulations with incorporations of the residue up to 50% to produce ceramic bricks and tiles. Another research [9] showed that in the case of using the waste to replace fine aggregates for concrete, satisfactory results were obtained in the proportion of 30%.

The use of kaolin waste is also seen as a substitute for cement, because there are percentages of kaolinite in the extraction, which has pozzolanic properties when kaolinization is done above 600 °C. This factor is found both in the extraction of mining waste and in the excavation of marine infrastructure in which the waste can be a substitute for cement [10].

Recycled aggregates from construction debris and kaolin waste have different physical characteristics, such as grain size and grain shape. Therefore, the introduction of these two residues to replace conventional aggregate can contribute to obtaining more adequate mixtures to produce concrete blocks in pneumatic machines.

Thus, the approach of this work seeks an alternative for the technically and environmentally adequate disposal of these two wastes and, thus, collaborate to reduce these negative impacts. The act of recycling waste can represent economic, social and environmental advantages, such as savings in the acquisition of raw materials, reduction of pollution generated by waste and preservation of natural raw material reserves. The objective of this work is to produce masonry concrete blocks with recycled aggregates from civil CDW and kaolin mining waste to be applied in non-structural elements. Here, we analyze comparatively the physical and mechanical aspects of the blocks obtained with and without the additions of recycled aggregates, observe their characteristics of water absorption, compressive strength, dimensional and mass variation.

2. Materials and methods

2.1. Experimental program

The methodology used was based on the comparative experimental research format, in order to replace the natural aggregates with kaolin residue in the fine part and at the same time replace the natural gravel with the CDW, in general compositions of percentages of 15%, 25% and 35% thus making a comparative analysis of the physical indices and compressive strength of the blocks.

The experiment was carried out at the Civil Construction Materials Laboratory (LMCC) of the Federal Institute of Ceará, Fortaleza campus, the production of the blocks was done at the company EcomatBrasil, which has 6 bar pneumatic pressing machines and a 320 L vertical concrete mixer.

The cement used was the Brazilian commercial type CPV-ARI with high initial strength, as it has a high reactivity and strength at low ages depending on the degree of grinding to which it is submitted, providing greater yield to the concrete, according to the Brazilian standard NBR 16697:2018 [11]. The water used was potable supplied by the Water Supply and Sewage Company (CAGACE).

The plasticizing additive used was Muraplast FK 320-MC. It should be noted that only in the preparation concrete was used an additive in the proportion of 0.25% in relation to the cement mass, as recommended by the manufacturer for use in concrete and precast.

The physical and mechanical tests of both the materials and the blocks were performed at the Civil Construction Materials Laboratory (LMCC) of the IFCE-Campus Fortaleza, Brazil.

In the tests, the Technical Standards were followed as described in Table 1. The process of sampling and reducing field samples for tests, the recommendations of ABNT NM 26: 2009 [12] and ABNT NBR NM 27: 2001 [13] standards were followed.

Table 1. Laboratory tests and the corresponding standards.

Property	Technical norm	Tested in
Unit Mass	NBR NM 45/2006	Aggregates
Specific mass	NBR MN 52/2009	Aggregates
water absorption	NBR NM 30/2000	Aggregates
Powder Material	NBR NM 46/2003	Aggregates
Granulometry	NBR 7211/2009	Aggregates
Dimensional stability	NBR 6136/2014	blocks
Variation Compression	NBR 6136/2014	blocks

The equipment used for the production of the blocks basically consisted of a 320 L inclined concrete mixer, with a concrete shaft, a vibropressing machine Model Atlantimaq E321 ACP Pneumatic up to 6 bar pressure, this machine having a 2 hp motor for form vibration (Figure 1). The manufacturing procedure of the blocks was to put the concrete in the machine with each mix determined, with the aid of a trowel and shovel to fill the form, a waiting for the vibration for compaction of 30 s per cycle, to apply the pneumatic pressing, producing 3 blocks per cycle. This time is enough to give a good compaction to the blocks produced, being the standard used by the factories as determined by Fernandes in the Ref. [14].

Figure 1. Pneumatic machine used in the manufacture of concrete blocks.

2.2. Formulation of the mixes used

The designed mix compositions were planned in order to reach the parameters established by Brazilian standard NBR 6136/2014 [15], in particular, the minimum value of the characteristic compressive strength for the Class C blocks for selling, which is 3 MPa. There is no common pattern of mix composition in the literature but the type of compaction machine to be used directly influences cement consumption [14]. A correlation between the moisture content of dry concrete and the use of machines with high compaction power (hydraulic) with the same moisture content it is possible to have a greater resistance than in manual and pneumatic equipment, as there is a reduction in voids. Thus, it was necessary to observe aspects related to the composition of the aggregate mixture, moisture content and the manufacturing and curing process. Table 2 summarizes that information about the replacement percentage of the materials in mixes.

Table 2. Percentage of aggregate replacement.

Composition	Fine aggregate replacement by kaolin waste	Coarse aggregate replacement by CDW
Mix 0	0%	0%
Mix 1	5%	10%
Mix 2	8%	17%
Mix 3	12%	23%

The normal setting multifunctional plasticizer additive (Muraplast FK 320) from the manufacturer MC-Bauchemie Brazil was used, in the proportion of 0.25%, respecting the adequate water/cement ratio for the molding of the blocks. The cement/aggregate ratio (1:6) by volume, with the ratio being 1:4:2 (1 cement; 4 stone dust; 2 crushed gravel) was the same as in the first stage, except for sand replacement. Table 3 shows the mix proportions used with the pneumatic vibration machine.

Table 3. Description of the mix proportions by volume used in the manufacturing of blocks.

	Mix 0	Mix 1	Mix 2	Mix 3
Cement	1	1	1	1
Stone dust	4	3.80	3.68	3.52
Kaolin waste	-	0.20	0.32	0.48
Crushed gravel	2	1.80	1.66	1.54
Waste const.	-	0.20	0.34	0.46
Water w/c ratio	0.55	0.55	0.55	0.55
Plasticizing additive	50 mL	50 mL	50 mL	50 mL

During the concrete cure, the evaporation of the water used in the concrete mixing was prevented and, thus, guaranteed the hydration of the cement components. These precautions are even more important for the manufacture of precast materials, such as concrete blocks, whose concretes have a lower w/c ratio than conventional concretes. To optimize the curing process of the blocks at this stage, the black plastic sheet for rain was also used to prevent premature evaporation of water, with the blocks being wet and covered for 7 d after the date of manufacture.

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3. Results

3.1. Construction and demolition waste

When determining the composition of the waste, it was assumed that it could not present impurities that could affect the performance of concrete blocks, such as paper, cardboard, wood, metal, glass and plaster. This sorting is done inside the plant when the truck arrives with waste and prepared for crushing. Therefore, these materials were discarded in the process of separation and characterization of the sample.

The composition of the visual characterization was made by the quartering method, following the procedure by NBR16915:2021 [12] and procedure by NBR 27:2001 [13] for laboratory tests. However, for the visual characterization, 1 kg of CDW was considered and sieved in a 4.8 mm sieve, with the passing material being discarded. The material characterized was only the material retained in this granulometry, because by NBR NM248:2001 [14]—Aggregate whose grains pass through a sieve with a 75 mm mesh opening and remain retained in the sieve with a mesh opening of 4.8 mm, they are characterized as coarse. In this work, this grain size was used to replace graded aggregates by CDW aggregates. As shown in Figure 2, the materials with the highest percentage in the recycled aggregate are concrete and mortar.

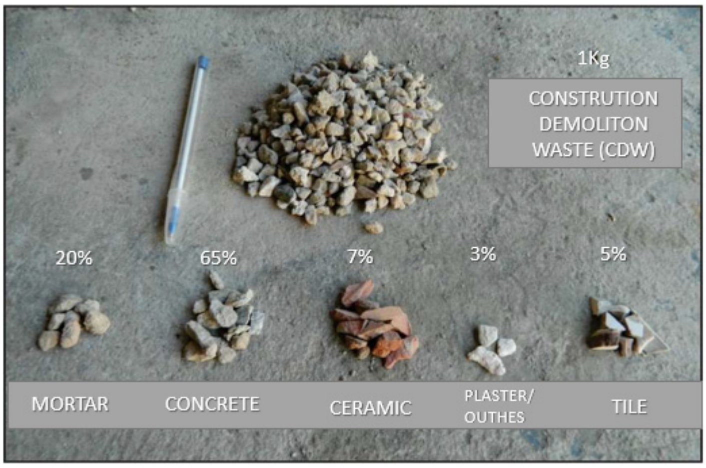

Figure 2. Composition of the CDW by visual characterization.

3.2. Kaolin residue composition

The manufacture of the blocks, only kaolin residues from the first stage were used, the so-called tantrum material with a particle size of material retained from the sieve 4.8 mm, to be adjusted for the manufacture of the blocks. This material consists mainly of kaolinite, muscovite and feldspar according to the chemical analysis already done by Menezes in Ref. [16] for this material taken from Mineradora Brazil Mineiro.

The composition of minerals in the kaolin waste, according to the extraction company, around 70% of the extracted ore is waste that is separated into two processes during the kaolin extraction. For the visual characterization, the same procedure as the CDW was performed, referring to the quaking and separation of 1 kg of the material. Figure 3 presents the mineral composition of the kaolin residue used.

Figure 3. Visual composition of the waste kaolin by visual characterization.

It shall be noted that, although the kaolin waste has kaolinite in its composition, in the present study the calcination of the waste to benefit the pozzolanic properties of kaolinite was not carried out.

The authors decided to do not carry out the calcination process because this (no calcination) was just the purpose of this exploratory research wherein the addition of this residue was incorporated with a maximum of 23%. For future research work and for a full-scale production of blocks with high percentages of kaolin waste, the calcination process shall be deeply evaluated especially for the economic and sustainability analyses.

3.3. Physical characterization of aggregates

The materials were tested according to NBR 45/2006 [17] which has the purpose of using the transformation from mass to volume with voids between the aggregate grains. The unit mass also serves as a parameter for classifying the aggregate in terms of density [18].

The specific mass of the aggregates used in the manufacture of the blocks was performed as determined by NBR NM 52 [19], which defines the specific mass as the ratio between the dry aggregate mass and its volume, excluding permeable pores.

Water absorption for fine aggregates was done following NM 30 [20]—Determination of water absorption for fine aggregates. According to the determination of NBR NM 46 [21] and the determination of the quantity of powdery material by NBR 7211 [22] for powdery materials, these are defined as mineral particles with a dimension less than 0.075 mm, including water-soluble materials, present in the aggregates. Table 4 describes the percentage of powdery materials used and presents the determination of water absorption of the materials used.

Table 4. Physical characterization unit mass, specific mass and aggregate absorption and percentage of fines of the materials used in manufacturing of the concrete blocks.

Aggregate	Bulk specific mass (g/cm^3)	Specific mass (g/cm^3)	Water absorption (%)	Percentage of fines (%)
Stone dust	1.43	2.62	0.97	10.5%
Gravel	1.40	2.66	0.85	0.98%
Kaolin Waste	1.35	2.63	0.26	4.06%
CDW	1.41	2.37	4.68	7.05%

3.4. Granulometric correction

Particle size corrections can be made for different purposes, in order to obtain a final product more suitable for different applications [23]. In the case under study, it was made with the aim of correcting the granulometry to fit within the limits of the curves suggested for concrete blocks, proposed by Fernandes in Ref. [14]. In this way, the lines used in the experiment were adjusted according to the granulometric ranges in Figure 4. The red curve is the representation of strokes made from 1:2:4 for all strokes with percent replacement. It is noticed that all the curves with the percentages overlap with small variations between the replacement percentages. Thus, it is possible to verify that the mixture of aggregates, for all waste additions, is within the limits suggested by Fernandes in Ref. [14], for the manufacture of concrete blocks.

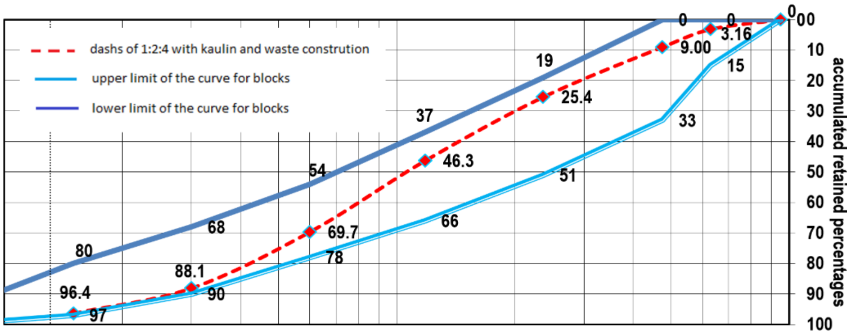

Figure 4. Particle size distribution of the CDW aggregate.

3.5. Determination of water absorption of blocks

To determine if there was a variation in the water absorption of the blocks as determined by NBR 12118/2013 for individual blocks in accordance with NBR 6136/2014 [15], there was a separation of samples for the absorption test, as determined by the procedures of NBR 61636/2014 [15], with the following absorption results being obtained in Table 5.

Table 5. Water absorption of blocks.

Block Type	Dry block weight (kg)	Block moist	Moisture (%)
Mix 0	8.07	8.69	7.07
Mix 1	8.5	9.09	6.50
Mix 2	8.2	8.84	7.14
Mix 3	8.01	8.64	7.34

3.6. Dimensional analysis and appearance of blocks

The measurements, texture and appearance of the blocks were measured both nominal and real and verified within the standardization determined by Brazilian standard NBR 6136/2014 [15], which establishes the standard measurements and classification for masonry blocks of sealing type 10 × 40. In Figure 5 it is possible to verify the texture and color of the blocks with the residues.

Figure 5. Appearance of concrete blocks.

The real dimensions, texture and appearance of the blocks were within the standardization determined by Brazilian standard NBR 6136/2014 [15]. Regarding the dimensional analysis, Table 6 presents the average data of 9 samples for width, height, length, wall thickness and minimum equivalent thickness of blocks produced from Mix 0, Mix 1, Mix 2 and Mix 3.

Table 6. Dimensional analysis of the blocks.

Block Type	Width (mm)	Height (mm)	Lenght (mm)	Area (mm^2)	Min. thickness of the walls (mm)	Min. equivalent thickness (mm/m)
Mix 0	90.05	189.00	389.00	35029.45	18	135
Mix 1	90.33	189.00	389.00	35139.67	18	135
Mix 2	89.67	188.67	389.67	34940.11	18	135
Mix 3	90.00	189.00	388.67	34980.00	18	134

Allowable tolerances in the dimensions of the blocks accordingly are ±2.0 mm for the width and ±3.0 mm for the height and for the length in relation to the dimension standard nominal (90 × 190 × 390 mm). With this, the comprehensive blocks are within the limits dimensional updated into standard. This analysis is important to verify if due an incorporation of waste in the blocks was altered by an eventual property of excessive swelling or shrinkage of the aggregates used, a point of change as default dimensions.

3.7. Block compressive strength

The initial procedure of compressive strength of the blocks occurred after 14 d of curing. The manufactured blocks were tested to rupture in a hydraulic compression press Model EMIC series 23 (Figure 6).

Figure 6. Testing the block compressive strength on the Machine Model EMIC series 23.

A grout capping leveling the imperfections was applied as determined by the standards of Brazilian standard NBR 6136/2014 [15]. The compressive strength values of the Blocks 1 to 6, tested at the age of 14 d, are presented the expressed in Table 7.

Table 7. Compressive strength recorded in the blocks tested (MPa).

	Age	Mix 0	Mix 1	Mix 2	Mix 3
Block 1	14 d	3.5	7.1	3.3	4.2
Block 2		2.3	4.6	4.2	6.1
Block 3		3.5	6.9	2.3	4.7
Block 4		4.5	4.6	3.3	4.5
Block 5		3.0	5.6	4.2	4.4
Block 6		4.7	6.4	3.1	3.7
Block 7	28 d	4.5	5.1	3.3	3.3
Block 8		4.2	7.3	4.2	4.2
Block 9		3.0	5.0	5.3	6.1
Block 10		4.5	6.9	5.3	4.7
Block 11		5.0	7.0	4.2	4.6
Block 12		5.5	6.7	3.3	4.3

At the age of 28 d there was another compressive strength test with the same capping procedure. The compressive strength values of the Blocks 7 to 12, tested at the age of 28 d, are presented in Table 7. The Figure 7 presents graphically the average compressive strength at the ages of 14 and 28 d with the corresponding standard deviation error bars for all mixes.

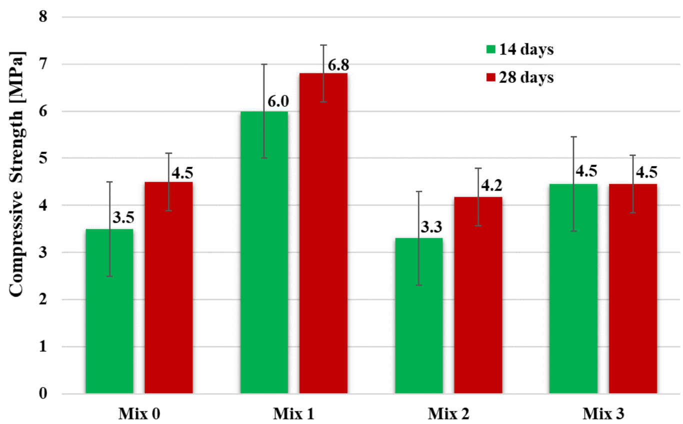

Figure 7. Compressive strength (average) at the ages of 14 and 28 d.

As determined by Brazilian standard NRR 6136/2014 [15], the averages of the compressive strength of the blocks must be expressed by the characteristic strength (f_{bk}). Determination of characteristic strength, which according to Fernandes [14] it is a kind of net value, polished, where they are taken in account possible errors in the production process. This procedure being more reliable than the average of block breakouts. The calculation of the characteristic strength values of the 14-d and 28-d blocks are shown in Table 8, considering the established values of Ψ of Brazilian standard NBR 6136/2014 [15] for a minimum quantity of 6 blocks. Analyzing Table 8, it is possible to verify that all types of blocks obtained compressive strength above 3 MPa which are classified as sealing blocks. The blocks with 28 d of Mix 1 had the highest results, but for economic and environmental reasons for this purpose of using the blocks, the ones used with the highest percentage of Mix 3 can be applied.

Table 8. Block characteristic strength at 14 and 28 d.

Block	f_{bk}^{14d} (MPa)	f_{bk}^{28d} (MPa)
Mix 0	3.04	4.08
Mix 1	5.78	6.25
Mix 2	3.02	3.98
Mix 3	4.01	3.99

4. Discussion

4.1. Analysis of blocks produced

The percentage mixtures of these two residues show that it is possible to replace conventional aggregate with CDW recycled aggregate and kaolin even with a percentage of 35%, without a significant loss of mechanical strength in relation to the mix with conventional aggregates and also maintaining adequate the dimensional and water absorption characteristics of the blocks. This percentage is quite significant because in large-scale production there would be a considerable use of these materials.

The mixtures with higher content of waste presented characteristic compressive strength values of approximately 4.0 MPa at the age of 28 d, well beyond the minimum required by the standard for Class C blocks for sealing blocks, this type of resistance is classified as Structural Class C and at the lower limit of Class B ($4.0 < f_{bk} < 8.0$) that is, block with structural function.

However, the most suitable percentage for the analyzed characteristics, taking into account the mechanical strength, was 15% of the waste that achieved the highest characteristic strength ($f_{bk} = 6.2$). The incorporation of material and probably a better arrangement of the particles in Mix 1, made it to have greater weight in relation to the other mixtures, demonstrates that there was a low rate of water absorption of the blocks and a high index of compressive strength. This better arrangement and accommodation of the compacted particles in Mix 1 lead to the difference in the percentage of absorption of the block that is 6.5%. It should be taken into account that the kaolin waste also has muscovite which is a material of very low hardness, in high percentages can harm the concrete of the mixtures.

The average between mixes of Mix 0, Mix 2 and Mix 3 demonstrates that there was no variation in water absorption rate, dry weight, and compressive strength. There was no significant dispersion in relative terms of the average value between the proposed mixtures and the reference mix (Mix 0).

Thus, for all analyzed percentages, the mixes could still be optimized, including the possibility of reducing cement consumption to produce blocks that meet the minimum requirements of Class C. The study, in general, indicates that the analyzed waste could be reused as a potential raw material, in technical, economic, and environmental aspects, thus giving a positive perspective for the use of recycled CDW aggregates, mixed with kaolin waste for the production of concrete blocks without a structural function. However, it is a fact that currently the reuse of materials for civil construction in the form of aggregates is still mostly in the field of research and there is little boldness in making large-scale replacements of natural materials. Despite the legal aspects, there is in a way an apparent accommodation of the sector, as there are still no factors of scarcity of natural materials to the point that the reuse of waste becomes, practically, an imposition.

To continue and enable the use of these wastes for other construction purposes, it would be necessary to carry out application studies of these materials, thus expanding the range of options for these wastes, such as:

- Application of residues on interlocking floors for paving.
- Use of other proportions and application percentages for the sealing blocks.
- Concrete for leveling floors and subfloors.
- Application in hollow elements and other cement artifacts such as balusters, curbs and precast concrete wall.
- Use of the mixture of the part with fine granulometry for mortars.

The alternatives to apply these wastes are diverse, as long as the technical standards and procedures are respected, aiming at both technical responsibility and issues of commercialization feasibility of these materials. The suggested alternatives point to a possibility of technological innovation together with the concern to establish materials sustainable with constructive alternatives.

5. Conclusions

The bibliographic survey it was found that large volumes of CDW are generated daily and a large part is disposed of irregularly and recycling does not even reach 10% of the volume generated. Based on the alternatives for recycling waste in the form of aggregates, the decision to merge the two materials (CDW and kaolin waste) was important, as there is a great demand for the development of environmentally appropriate solutions for the disposal of this waste. On the other hand, up to the present moment, no works were found in the researched literature that would develop an alternative of reuse involving the simultaneous use of the two analyzed wastes.

The gravimetric composition of recycled aggregates obtained through visual analysis indicated that the CDW aggregate has 65% concrete, 20% mortar, 7% ceramic, 5% tiles and 3% other materials. While kaolin residue has 83% Quartz, 13% Muscovite and 4% Kaolinite. Even with the presence of mica and ceramic wastes in the quantities observed, it was possible to produce the blocks within the standards of the technical reference standard. It should be noted that this is a positive aspect, as the separation of these materials would make the process more expensive and, in some situations, unfeasible due to the demand for the materials used in the manufacturing process of the blocks.

However, it was observed that the type of recycled aggregate from mixed civil construction waste used presents characteristics and physical indices different from aggregates only of the ceramic type or only of the gray type, containing mortar, concrete and concrete blocks.

In relation to the physical properties of recycled aggregates, the analyzed indexes presented adequate values for the use of materials in the form of aggregates. The relatively high absorption observed in the 4.68% CDW did not prove to be a limiting factor for the preparation of dosages and sample production. Regarding the granulometry, it was possible, with the mixture of aggregates, to establish granulometric curves within the optimal range to produce blocks. This proved not to be a limiting factor in the loss of plasticity in the production of blocks.

The application of kaolin in the construction sector is extremely important because this raw material is used in various sectors. The extraction process of kaolin leaves residues of the order of almost 60%. With this exploratory research, it was demonstrated that there are possibilities of uses for this material that sometimes goes to landfills or disposal areas. Masonry blocks for civil construction application demonstrates certain viability, both in the substitution of aggregates and cement.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. Goldemberg J, Agopyan V, John VM (2011) *O desafio da Sustentabilidade na Construção Civil*, 1 Ed., São Paulo: Blucher, 19–61.
2. Abrelpe, Brazilian Association of Public Cleaning and Special Waste Companies, Panorama dos Resíduos Sólidos no Brasil (Panorama of solid waste in Brazil), 2019. Available from: https://abrelpe.org.br/download-panorama-2018-2019/.
3. Brasil. Departamento Nacional de Produção Mineral (DNPM) (2012) *Sumário Mineral 2010*, Available from: https://www.gov.br/anm/pt-br/centrais-de-conteudo/dnpm/sumarios/sumario-mineral-2010.
4. Popp JH (1995) *Geologia Geral*, 4 Eds., Rio de Janeiro RJ: Technical and scientific books publisher.
5. Biffi G (1997) *Il Grés porcellanto Manuale di Fabricazione e Tecniche di Impiego*, Italy: Faenza Editrice Editorial Group, 312. Available from: http://biblioteca.hiposter.ru/book/il_gres_porcellanato_manuale_di_fabbricazione_e_tecniche_di_impiego_92173-free_download.html.
6. Hood RS (2006) Analysis of the technical feasibility of the use of waste of construction and demolition as small recycled aggregate in concrete blocks for paving [Dissertation]. Universidade Federal do Rio Grande do Sul (in Portuguese). Available from: https://lume.ufrgs.br/handle/10183/12112.
7. Hendriks CF, Nijikerk AA, van Koppen AE (2007) *O ciclo da construção*, 2Eds., Brasília: Universidade de Brasilia.
8. Menezes RR, Farias FF, Oliveira MF, et al. (2009) Kaolin processing waste applied in the manufacturing of ceramic tiles and mullite bodies. *Waste Manage Res* 27: 78–86.
9. Seeni A, Selvamony C, Kannan SU, et al. (2012) Experimental study of partial replacement of fine aggregate with waste material from China clay industries. *IJCER* 2: 167–171.

10. Du H, Pang SD (2018) Value-added utilization of marine clay as cement replacement for sustainable concrete production. *J Clean Prod* 198: 867–873.
11. Associação Brasileira de Normas Técnicas (ABNT) (2018) Portland cement with high initial strength CPV-5. Portland cement–Requirements. ABNT NBR 16697. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
12. Associação Brasileira de Normas Técnicas (ABNT) (2021) Aggregates sampling. ABNT NBR 16915, 1 Ed. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
13. Associação Brasileira de Normas Técnicas (ABNT) (2021) Aggregates—Reducing field samples to laboratory test size. NM 27: 2001. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
14. Fernandes ID (2016) *Blocos e Pavers—Produção e Controle de Qualidade*, São Paulo: Treino Assessoria e Formação, 4 Eds.
15. Associação Brasileira de Normas Técnicas (ABNT) (2016) Hollow concrete blocks for concrete masonry–Requirements. ABNT NBR 6136: 2014. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
16. Menezes RR, de Araújo Neves, G, Ferreira HC, et al. (2002) Recycling of granite industry waste from the northeast region of Brazil. *Manag Environ Qual* 13: 134–141.
17. Associação Brasileira de Normas Técnicas (ABNT) (2009) Determination of aggregates–Determination of unit mass and void volume. NBR 45:2006, 4 Eds. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
18. Associação Brasileira de Normas Técnicas (ABNT) (1982) Aggregates in loose state–Mass determination. NBR 7251, 2 Eds. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
19. Associação Brasileira de Normas Técnicas (ABNT) (2009) Fine aggregate determination of specific mass and specific mass. NBR NM 52, 2 Eds. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
20. Associação Brasileira de Normas Técnicas (ABNT) (2000) Fine aggregate determination of water absorption. NBR NM 30, 2 Eds. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
21. Associação Brasileira de Normas Técnicas (ABNT) (2003) Fine aggregate determination of fine material that passes through the 75 µm sieve, by washing. NBR NM 46, 2 Eds.
22. Associação Brasileira de Normas Técnicas (ABNT) (2009) Aggregates for concrete–Specification. ABNT NBR 7211:2009, 2 Eds. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.
23. Associação Brasileira de Normas Técnicas (ABNT) (2003) Aggregates—Sieve analysis of fine and coarse aggregates. NBR NM 248: 2003. Available from: https://www.normas.com.br/produto/normas-brasileiras-e-mercosul/pesquisar.